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Variation of temperature in the lower stratosphere above Larkhill and Lerwick

(Addendum to M.R.P. 819)

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Introduction and Summary

The numbers of observations for 60 mb. used in the analysis described in the previous paper, M.R.P. 819(1), were not large. Moreover, data for all hours of observation, day and night, were used. Because of the comparatively scanty data and the possibility that radiation errors might result in correlation coefficients being erroneously small, the stratospheric correlation coefficients were computed again for Larkhill and Lerwick using all available data for the level of 60 mb. for specified hours of observation, day and night separately. The important result obtained previously, namely that the relation between temperature and the height of the 300 mb. surface and tropopause pressure respectively, falls off rapidly between 150 and 60 mb. was confirmed, but the seasonal variations in these relations appear to be less marked than was indicated in the earlier paper.

1. Data

As in M.R.P. 819 the analysis was restricted to data for the four mid-season months, January, April, July and October. All observations reaching the level of 60 mb. at 00 and 12h. G.M.T. before 1948 and at 03 and 15h. G.M.T. in 1948 and later years at Larkhill and Lerwick were used and values of the height of the 300 mb. surface (H_{300}), the pressure of the tropopause (P_T), and temperatures at levels 150, 100 and 60 mb. (T_{150}, T_{100}, T_{60} respectively) were extracted, the day and night observations being treated separately. For January and April at Lerwick and April at Larkhill so few observations were available for the selected hours that it was necessary to use data for other hours of observation, the data being grouped according to whether the observations were in daylight or darkness. These data provided comparable sets of observations at each of the three levels, 150, 100 and 60 mb. in contrast with the data used in M.R.P. 819 which embraced many more observations at 150 mb. than at 60 mb. whence there was always the possibility that observations at the higher level, through some bias or another, might not be in the same class as the observations from lower levels.

Correlation coefficients between H_{300} and T_{150}, T_{100} and T_{60} respectively and between P_T and the same temperatures were computed. The results are given in Tables I and II for Larkhill and Lerwick respectively. Results for day and

/night

night are given separately although in several months the figures for one or other of day or night have no great significance. They serve, however, as a useful reminder of the limitations of correlation analysis and help in assessing the accuracy of the results.

2. Discussion

(a) Larkhill. Table I.

The day and night sets appear to be consistent and there is no significant difference in the correlation coefficients from those given in Table I of M.R.P. 819 except that values at 60 mb. are generally smaller than in M.R.P. 819.

As a means of judging whether the selected observations used in the preparation of Table I are representative of general conditions in the stratosphere, Table III was prepared comparing some of the statistics in Table I with similar statistics for all observations in the period 1946-1950. In some months the standard deviations differ appreciably but considering the numbers of observations it can be said that the selected sets are representative of general conditions. The majority of the day/night observations used in compiling Table I were separated by more than 24 hours in time. Persistence effects will thus be small and the effective number of observations must be little short of the actual number used. (See discussion in M.R.P. 819).

(b) Lerwick. Table II.

Here there are significant differences between the night and day except in October. In January the day correlation coefficients show weaker relationships than the night at each of the stratospheric levels. Table IV, prepared as Table II to compare the sets of selected observations with the more general observations, shows that for the day observations the pressure of the tropopause was much less variable and the temperature at 150 mb. slightly less variable than in general. The night set with nearly double the number of observations is much more in agreement with the general unselected data. It is deduced that the day coefficients are not representative and that the night coefficients are more likely to represent the general relations. The differences between the day and night correlation coefficients in April and July are also almost certainly not significant as the number of night observations is small in each case; in July there is small variability in P_T and T_{150} for the night observations.

To get a more representative set of correlation coefficients for January and to reduce sampling errors the day and night observations were combined. The resulting statistics are given in Table V. Data are sufficient to make only a rough estimate of diurnal variation of temperature at 60 mb. as observed by radio-sonde at Lerwick in January. The statistics in Table II would suggest a figure of 2-3°F. A comparable figure for Larkhill would be 4-5°F. from the data for 1946-1950(2) but rather less (3-4°F.) from the figures in Table I assuming that diurnal variation at 150 mb. is of the order 1°F. As discussed in M.R.P. 819 such a small variation between day and night observations would have a very small effect on correlation coefficients computed from these observations combined when the standard deviation of temperature is three or four times as large as the semi-diurnal range.

The correlations for January in Table V and for daylight for April, July and October in Table II do not show great differences from those in Table II of M.R.P. 819. The other statistics in Tables II and V compared with the statistics for unselected ascents in Table IV show that these selected data for high altitude are fairly representative of general conditions.

The effective number of observations must, as in Table I, be only a few less than the number of observations.

/3.

3. Variation of the correlation coefficients with height

The correlation coefficients in Tables I, II and V show a marked decrease with decreasing pressure. The direct relationship between two variables varies as the square of their correlation coefficient. Accordingly Table VI was prepared giving the ratio of the squares of the correlation coefficients for T_{60} and T_{150} (compare Table VII, M.R.P. 819). It is a reasonable inference from these figures that the influence of the disturbances of the troposphere in middle latitudes on temperature in the stratosphere is reduced to at least a half between 150 and 60 mb. and for much of the year to one-fifth or one-third.

4. Variation of the correlation coefficients with season

At Larkhill (Table I) the correlation coefficients are lowest in January and highest in July and October. In M.R.P. 819 the coefficients for January are almost as great as those for October. Except at 60 mb. the differences between the seasons are not large. Table VI shows that the decrease with height in the relationship between stratospheric temperatures and H_{300} and P_T respectively is least in October and greatest in January and April.

At Lerwick (Tables II and V) the correlation coefficients are least in January, not very much greater in April and largest in October. January and October have the greatest and least reductions respectively in the coefficients between the 150 and 60 mb. levels (Table VI). The greatest correlation coefficients (October) have similar values at Larkhill and Lerwick but the coefficients at Lerwick are lower than at Larkhill in January and April especially at 60 mb. where the differences between the coefficients for H_{300} are certainly significant. The same types of differences were noted in M.R.P. 819.

It was suggested in M.R.P. 819 that the variability in temperature distribution over Lerwick in January, where two different stratospheric regimes can occur, is the cause of the lower correlations in that month. This argument has some force. It is noted, however, that as for H_{400} at Arctic Bay (M.R.P. 819, Table III), it is the H_{300} correlations which are markedly reduced, the correlations involving P_T being not much less than in summer. Much of the relation between pressure at the tropopause and stratospheric temperature must arise from the close relation between vertical motion at the tropopause and vertical motion within the lower stratosphere; a low tropopause can be partly caused by subsidence and this subsidence would increase the temperature in the lower stratosphere; the reverse would apply for a high tropopause. Presumably the moderate correlation between P_T and temperature in the lower stratosphere in winter and spring arises mainly from this effect of vertical motion. The surprising fact, however, is that although P_T and H_{300} are still moderately correlated in January and April the H_{300} correlations with stratospheric temperatures are lower than the P_T correlations. Table VII shows the correlations between H_{300} and P_T for the data used in preparing Table II and these may be compared with similar coefficients for larger numbers of observations in M.R.P. 819, Table II; it is seen that the correlations are always about -0.7 to -0.8. There is nothing inconsistent in the statistics, however, since a correlation coefficient of 0.7 merely signifies roughly a 50% relation, assuming the relationship to be linear. All the factors resulting in the reduced H_{300} correlations in winter and spring at Lerwick are not obvious from this analysis, and further work is required to throw light on this interesting point.

In M.R.P. 819 the seasonal variation of ozone was compared with the seasonal variation of these correlation coefficients at Lerwick and Larkhill. The more reliable figures given here in Tables I, II and V certainly show that the correlation coefficients for the level 60 mb. (19 km.) which is not far below the ozone levels (20-35 km.) are, in general, least in January and April and greatest in October. The ozone maximum is in March and the minimum in October (see, for example, reference (3)) and the seasonal variation in the above correlation coefficients may thus well be associated with the variation in ozone, but this is not proved and the mechanism relating to it is obscure.

/Acknowledgment

Acknowledgment

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REFERENCES

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2. - — Upper Air Data, Larkhill, 1946-1950. Met. Off. London, M.O. 555, Part I, 1952.

3. Normand, Sir Charles — Atmospheric Ozone and Upper Air Conditions. Q.J. Roy. Met. Soc., 79, 1953, page 39.

TABLE I

Stratospheric Statistics for Larkhill (51° 12'N, 01° 48' W)

Period 1944-1952 (-1953 for January)

	H_{300} and T			P_T and T						H_{300} and T			P_T and T					
	ρ	$\bar{H}_{300}$ (10's of ft.)	$\sigma_{H_{300}}$ (10's of ft.)	ρ	$\bar{P}_T$ (mb.)	σ_{P_T} (mb.)	$\bar{T}$ (°F.-ve)	σ_T (°F.)	n	ρ	$\bar{H}_{300}$ (10's of ft.)	$\sigma_{H_{300}}$ (10's of ft.)	ρ	$\bar{P}_T$ (mb.)	σ_{P_T} (mb.)	$\bar{T}$ (°F.-ve)	σ_T (°F.)	n
Night 00,03 GMT			**JANUARY**									**JULY**						
T_{150}	-0.61	2920	63	0.67	220	43	76.3	10.8	52	-0.86	3090	45	0.82	221	45	63.4	7.7	41
T_{100}	-0.53	2920	63	0.50	220	43	78.5	6.9	52	-0.79	3090	45	0.65	221	45	64.3	4.9	41
T_{60}	-0.28	2920	63	0.29	220	43	80.4	7.1	52	-0.55	3090	45	0.41	221	45	61.7	4.0	41
Day 12,15 GMT																		
T_{150}	-0.60	3000	60	0.69	212	43	73.6	10.1	62	-0.71	3100	38	0.72	212	29	58.6	7.6	73
T_{100}	-0.67	3000	60	0.63	212	43	73.4	8.4	62	-0.70	3100	38	0.61	212	29	58.1	6.4	73
T_{60}	-0.27	3000	60	0.35	212	43	74.8	8.7	62	-0.40	3100	38	0.44	212	29	51.4	6.5	73
Night 00,03,21 GMT			**APRIL**									**OCTOBER**						
T_{150}	-0.77	3000	58	0.80	233	43	67.6	7.2	55	-0.80	3030	70	0.72	222	57	72.4	9.2	56
T_{100}	-0.67	3000	58	0.71	233	43	69.4	5.7	55	-0.73	3030	70	0.61	222	57	74.5	7.6	56
T_{60}	-0.22 *	3000	58	0.37	233	43	69.9	5.0	55	-0.56	3030	70	0.40	222	57	72.8	5.2	56
Day 12,15 GMT																		
T_{150}	-0.69	3010	58	0.74	230	45	63.4	7.2	89	-0.88	3040	62	0.82	219	46	69.0	8.4	79
T_{100}	-0.64	3010	58	0.61	230	45	63.8	5.7	89	-0.79	3040	62	0.69	219	46	69.8	7.0	79
T_{60}	-0.24	3010	58	0.39	230	45	61.5	5.7	89	-0.57	3040	62	0.49	219	46	66.7	5.8	79

H_{300} = height of 300 mb. surface $\sigma_{H_{300}}$ = standard deviation of H_{300} T_{150}, T_{100}, T_{60} = temperature (°F.) at 150, 100, 60 mb. respectively

P_T = pressure at the tropopause σ_T = standard deviation of T ρ = appropriate correlation coefficient

n = No. of observations σ_{P_T} = standard deviation of P_T.

* Not significant at 5% level

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TABLE II

Stratospheric Statistics for Lerwick (60° 08'N, 01° 11' W)

Period 1944-1952 (-1953 for January)

	H_{300} and T			P_T and T						H_{300} and T				P_T and T					
	ρ	$\bar{H}_{300}$ (10's of ft.)	$\sigma_{H_{300}}$ (10's of ft.)	ρ	$\bar{P}_T$ (mb.)	σ_{P_T} (mb.)	$\bar{T}$ (°F.-ve)	σ_T (°F.)	n	ρ	$\bar{H}_{300}$ (10's of ft.)	$\sigma_{H_{300}}$ (10's of ft.)	ρ	$\bar{P}_T$ (mb.)	σ_{P_T} (mb.)	$\bar{T}$ (°F.-ve)	σ_T (°F.)	n
Night 00,03,06,18 and 21 GMT			JANUARY							**Night** 00 GMT			JULY						
T_{150}	-0.58	2910	71	0.74	242	55	72.8	9.3	88	T_{150}	-0.26 *	3040	32	0.49	224	21	57.3	4.9	22
T_{100}	-0.30	2910	71	0.53	242	55	75.9	8.3	88	T_{100}	-0.32 *	3040	32	0.33 *	224	21	57.9	3.6	22
T_{60}	-0.11*	2910	71	0.32	242	55	81.2	9.1	88	T_{60}	+0.07 *	3040	32	-0.11 *	224	21	55.1	3.2	22
Day 12,15 GMT										**Day** 12,15 GMT									
T_{150}	-0.19*	2930	71	0.46	230	39	72.4	8.8	46	T_{150}	-0.79	3050	55	0.77	242	38	50.8	7.6	70
T_{100}	+0.08*	2930	71	0.19*	230	39	74.7	7.9	46	T_{100}	-0.71	3050	55	0.61	242	38	49.0	5.4	70
T_{60}	+0.22*	2930	71	0.03*	230	39	78.4	10.2	46	T_{60}	-0.39	3050	55	0.27	242	38	44.2	4.4	70
Night 00,03,21 GMT			APRIL							**Night** 00,03 GMT			OCTOBER						
T_{150}	-0.70	2950	75	0.79	260	53	59.8	7.3	19	T_{150}	-0.81	3010	68	0.72	217	47	71.2	9.5	61
T_{100}	-0.73	2950	75	0.73	260	53	62.1	5.1	19	T_{100}	-0.76	3010	68	0.64	217	47	71.1	7.9	61
T_{60}	-0.40*	2950	75	0.49	260	53	63.9	4.6	19	T_{60}	-0.57	3010	68	0.50	217	47	71.5	5.8	61
Day 12,15 GMT										**Day** 12,15 GMT									
T_{150}	-0.54	2940	66	0.58	277	55	55.7	7.8	75	T_{150}	-0.83	3000	75	0.78	232	53	65.8	10.0	91
T_{100}	-0.35	2940	66	0.54	277	55	57.7	6.3	75	T_{100}	-0.82	3000	75	0.76	232	53	65.6	7.7	91
T_{60}	-0.07*	2940	66	0.28	277	55	57.3	6.0	75	T_{60}	-0.61	3000	75	0.55	232	53	64.5	6.1	91

For explanation of symbols, see Table I

* Not significant at 5% level

TABLE III - Comparison of sets of upper air data: Larkhill

	$\bar{H}_{300}$ (10's of ft.)	σH_{300} (10's of ft.)	$\bar{P}_T$ (mb.)	σP_T (mb.)	$\bar{T}_{150}$ (-°F.)	σT_{150} (°F.)	n
January							
Selected night ascents	2920	63	220	43	76.3	10.8	52
Selected day ascents	3000	60	212	43	73.6	10.1	62
All observations 1946-1950 *	2969	77	236	54	68.9	9.7	528 /
April							
Selected night ascents	3000	58	233	43	67.6	7.2	55
Selected day ascents	3010	58	230	45	63.4	7.2	89
All observations 1946-1950 *	2979	67	243	56	63.3	8.9	467/
July							
Selected night ascents	3090	45	221	45	63.4	7.7	41
Selected day ascents	3100	38	212	29	58.6	7.6	73
All observations 1946-1950 *	3081	44	223	39	60.1	7.7	560 /
October							
Selected night ascents	3030	70	222	57	72.4	9.2	56
Selected day ascents	3040	62	219	46	69.0	8.4	79
All observations 1946-1950 *	3041	66	219	50	73.0	8.8	574 /

For explanation of symbols, see Table I.
/ Number of observations of T_{150}.
* From M.O. 555, Part 1; statistics for H_{300} refer to 1948-1950 only.

TABLE IV - Comparison of sets of upper air data: Lerwick

	$\bar{H}_{300}$ (10's of ft.)	σH_{300} (10's of ft.)	$\bar{P}_T$ (mb.)	σP_T (mb.)	$\bar{T}_{150}$ (-°F.)	σT_{150} (°F.)	n
January							
Selected night ascents	2910	71	242	55	72.8	9.3	88
Selected day ascents	2930	71	230	39	72.4	8.8	46
All observations 1946-1950 *	2895	76	254	57	69.0	9.5	502 /
April							
Selected night ascents	2950	75	260	53	59.8	7.3	19
Selected day ascents	2940	66	277	55	55.7	7.8	75
All observations 1946-1950 *	2912	65	281	57	55.2	9.1	489 /
July							
Selected night ascents	3040	32	224	21	57.3	4.9	22
Selected day ascents	3050	55	242	38	50.8	7.6	70
All observations 1946-1950 *	3033	51	247	37	51.0	7.0	541 /
October							
Selected night ascents	3010	68	217	47	71.2	9.5	61
Selected day ascents	3000	75	232	53	65.8	10.0	91
All observations 1946-1950 *	2967	71	234	53	66.9	9.9	549 /

For explanation of symbols, see Table I.
/ Number of observations of T_{150}.
* From M.O. 555, Part 2; statistics for H_{300} refer to 1948 -1950 only.

TABLE V - Stratospheric statistics for Lerwick in January
Day and night combined: 1944-53

	H_{300} and T				P_T and T					
	ρ	H_{300} (10's of ft.)	$\sigma_{H_{300}}$ (10's of ft.)		ρ	$\bar{P}_T$ (mb.)	σ_{P_T} (mb.)	$\bar{T}$ (-°F.)	σ_T (°F.)	n
T_{150}	-0.45	2920	71		0.66	238	50	72.6	9.1	134
T_{100}	-0.16*	2920	71		0.43	238	50	75.5	8.1	134
T_{60}	+0.03*	2920	71		0.21	238	50	80.2	9.9	134

For explanation of symbols, see Table I.

* Not significant at 5% level.

TABLE VI - Ratio of squares of correlation coefficients for T_{60} and T_{150}

	January		April		July		October		Year ##	
	H_{300}	P_T	H_{300}	P_T	H_{300}	P_T	H_{300}	P_T	H_{300}	P_T
Larkhill										
Night	0.21	0.19	0.08*	0.21	0.41	0.25	0.49	0.31		
Day	0.20	0.26	0.12	0.28	0.32	0.37	0.42	0.36	0.25	0.31
Lerwick										
Night	0.03*	0.19	0.33*	0.38	0*	0.05*	0.49	0.48		
Day	0*	0.004*	0.02*	0.23	0.24	0.12	0.54	0.50	0.12	0.21

* Correlation for T_{60} (or T_{150}) not significant at 5% level. If correlation coefficient changes sign from 150 to 60 mb., ratio counted as zero.

Values here are the squares of the mean ratios of the daylight coefficients for T_{60} and T_{150} for all four months, except for January, Lerwick where the correlation coefficients for all hours combined were used instead of the daylight values.

TABLE VII - Correlation coefficients between H_{300} and P_T
High altitude ascents at Lerwick

	Night		Day	
	Correlation Coefficient	No. of Obs.	Correlation Coefficient	No. of Obs.
January	-0.77	88	-0.87	46
April	-0.85	19	-0.79	75
July	-0.69	22	-0.86	69
October	-0.75	61	-0.83	91